



Global climate change impacts on children

September 2019

VISIT...

LANZAROTE
Caliente.COM

Global climate change impacts on children

September 2019

Report by Climate Analytics

Authors: Inga Menke, Carl-Friedrich Schleussner

Cover image

Children in flooded streets of Jakarta, Indonesia.

Kent Clarke CC BY-NC-ND 2.0

Table of contents

1. Summary	2
2. Demographic developments (global).....	4
2.1. Likelihood of children to experience 1,5, 2 and 3°C	5
3. Observed and projected impacts.....	5
3.1. Representative Concentration Pathways – temperature warming	5
3.2. Temperature increase globally.....	6
3.3. Sea Level Rise globally	7
3.4. Intensity of weather events	9
3.5. Impacts on different sectors	14
3.6. Health	19
3.7. Societal impacts.....	25
4. Loss and Damage.....	28
<i>Bibliography</i>	<i>30</i>

1. Summary

There are currently 2.3 billion children under the age of 18 living on earth who are among the group of people most vulnerable to climate change. Already today the global average temperature is 1°C above pre industrial times. The likelihood of children to live in a 1.5°, 2° and 3° world is significantly higher than for adults. Almost all children will experience 1.5° warming. Mitigation efforts of countries to date are insufficient to achieve the 1.5°C limit (or lower) of the Paris Agreement, but rather set the world on track towards a 3°C warming by the end of the century. Under such a pathway, 92% of all 16-year-old children alive today are expected to live in a 2°C warmer world and 4% will experience a 3° warmer world.

Global sea levels have risen by about 20cm since pre-industrial times. Current projections show a risk for **global sea level rise** of up to 1m by 2100. Sea level rise will continue for centuries to millennia after emissions have been reduced to zero and could amount to many meters. Only limiting warming to 1.5°C in line with the Paris Agreement may hold long-term sea level rise in 2300 below 1m. Every delay of 5 years in peaking of emissions will lead to a 20cm increase in sea level rise over that time frame.

Extreme events will increase in frequency and intensity. Heat waves and extreme hot summers such as the 2003 Central European hot summer, which would have been a 1 in a 100-year event without climate change, is currently projected to be a 1 in a 4-year event and is projected to happen almost every other year under 1.5° warming. Six out of 10 central European summers would be like that or warmer if there is a 2°C warming. Even at 1.5°C warming in comparison to present day warming levels, globally twice as many megacities will be exposed to heat stress exposing up to 250 million additional people to deadly heat wave conditions by 2050.

Tropical cyclones as severe as Irma, Harvey or Maria which hit the Caribbean in 2017, are likely to reoccur or worsen in strength, with global warming.

The IPCC has identified five key “**reasons for concern**” summarizing the **impacts of climate change**. Risks and impacts related to all five reasons will worsen to high or even very high if warming of 1.5°C is exceeded. Without additional substantial emissions reduction, children of today will live half their lives in a world characterized by high climate risks across a broad range of impacts.

Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)

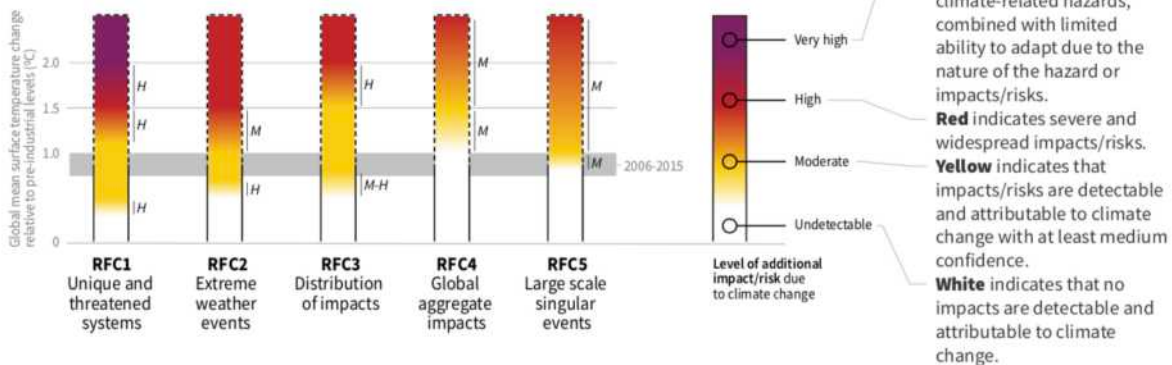


Figure 1: How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems. Source: IPCC, 2018

The **tropical rainforest biomass** is expected to reduce due to deforestation, fire and change in biomes. The biomass expected to be lost between 1.5°C and 3°C warming levels - doubles from 20 to 40%.

Crop yield is expected to decrease in most regions increasing the risk for food shortage. The West Sahel zone is projected to face serious food security issues above 2°C.

The number of people exposed to **water stress** will increase with rising temperatures. At 1.5°C warming an increase of 4% more people of the world population are expected to be exposed to water stress, while 8% more people will be exposed at 2°C warming.

Increasing temperatures have an impact on **biodiversity** as the biomes shift and habitats are destroyed. The expected losses for insects, plants and vertebrates are twice to three times as large at 2°C warming levels than at 1.5° warming.

Health impacts will disproportionately affect children and will worsen with increasing temperatures. Child mortality especially for children below five years of age will increase due to the higher vulnerability of children which includes lower tolerance for heatwaves, air pollution, and food deprivation/undernutrition. 88% of the existing burden of diseases as a result of climate change is put on children under the age of five.

Occupational health will become an increasing challenge particularly in sectors that require manual labor outside such as agriculture and construction, which will lead to economic loss particularly in tropical and sub-tropical countries. In 2017 an estimated 153 billion **hours of labor** were lost which equals an increase of 62 billion hours in comparison to the year 2000. 80% of the losses are linked to the agricultural sector.

The costs of preventing workplace heat-related illnesses through worker breaks suggest that the difference in economic loss between 1.5°C and 2°C could be approximately 0.3% of global gross domestic product (GDP) in 2100.

Since 2008, climate-related **displacement** has affected an estimated 22.5 million people per year on average - equivalent to 62,000 people every day. Populations of Small Island Developing States in particular are being threatened by sea level rise and are threatened for their very survival. In response to that existential threat, Kiribati was the first island state to actually purchase land in Fiji to consider the migration of a whole nation due to future sea level rise which will make the island uninhabitable.

Already today at about 1°C global warming, **poverty** and disadvantage have increased and are likely to increase even further with rising temperatures. At approximately 1.5°C of global warming, climate change is expected to be a poverty multiplier. Climate change alone could force 3 million to 16 million people into extreme poverty, mostly through impacts on agriculture and food prices.

Sea level rise and other extreme events will impact **Cultural heritage**. A global analysis of sea level rise risk to 720 UNESCO Cultural World Heritage sites projected that about 47 sites might be affected under 1°C of warming, with this number increasing to 110 and 136 sites under 2°C and 3°C, respectively.

Soft and hard limits of adaptation will cause irreversible **loss and damage** already for warming levels at around 1.5°C and even more so if 1.5°C is exceeded. Exceeding the limits of adaptation can trigger escalating losses or result in undesirable transformational changes such as loss of livelihoods in Small Island Developing States.

2. Demographic developments (global)

Based on the 2019 revision of the United Nation's population prospects, the world is currently populated by about 2.5 billion children, up to the age of 19, comprising more than a third of the world's total population (United Nations, 2019). The youngest populations tend to reside in the least developed countries which are still undergoing early phases of demographic transitions and are still experiencing high fertility rates.

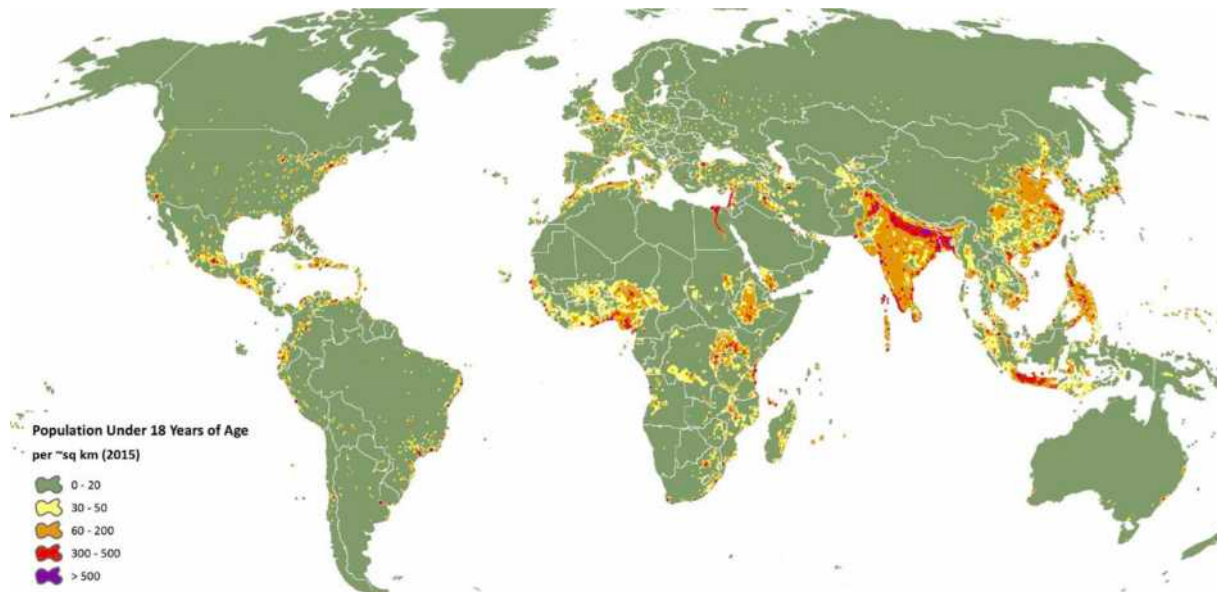


Figure 2: Global map of where the 2.3 billion children currently live (population below the age of 18). Source: UNICEF, 2015

2.1. Likelihood of children to experience 1.5, 2 and 3°C

Today's children are expected to live longer, and be healthier and better educated than any of their ancestors, though with large disparities between countries. An average 16-year-old citizen of the world is expected to live until the age of 82 (World Data Lab, 2019), with a 98% probability to experience the 1.5°C world (~2035), 92% for a 2°C world (~2055). About 4% of today's teenagers are expected to live until the end of the century when the current emissions pathways could bring about a 3°C warmer climate (Climate Action Tracker, 2018).

3. Observed and projected impacts

Today the impacts of climate change are noticeable around the world. With increasing global warming, the impacts on humans and natural systems will increase. Demographic developments increase the likelihood of children to experience a 1.5°, 2° and even 3° warmer world. Impacts from these global temperature increases are considered in the analysis of projected impacts.

3.1. Representative Concentration Pathways – temperature warming

Representative Concentration Pathways (RCPs) are a suite of scenarios considering future emissions and concentrations of greenhouse gases, aerosols, and land use (Moss et al., 2008). The International Panel on Climate Change (IPCC) and the climate modelling community use four different scenarios named after their radiative forcing potential (RCP 2.6, 4.5, 6.0, 8.5)(Moss et al., 2010). Each RCP is associated with an approximation for the range of the temperature increase by 2100 in comparison to pre-industrial times. The table below shows the median temperature estimate of this range. RCP2.6 is the pathway compatible with the Paris Agreement and would lead to about 1.5°C by the end of the century. RCP4.5 translates to about 2.5°C warming by 2100, RCP6.0 to about 3° warming and is corresponding to a business-as-usual approach to emissions reduction, in line with current policies (Climate Action Tracker, 2018). RCP8.5 is a high emissions scenario reaching more than 4°C by 2100. Many studies in climate research use a subset of the RCPs and hence do not provide estimates

of impacts under all warming levels. In the analysis on global and national impacts, we will refer to the expected temperature increase by 2100 rather than the RCP. For high emission scenarios either RCP8.5 and 6.0 are used, while 2.6 is consistently used for a low emission scenario.

Name	Expected temperature increase in 2100 (median)
RCP2.6	1.6°C
RCP4.5	2.4°C
RCP6.0	2.8°C
RCP8.5	4.3°C

Table 1: Representative Concentration Pathways scenarios and their approximate temperature increase by 2100 in comparison to pre-industrial times). Source: Field et al., 2014)

3.2. Temperature increase globally

Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (likely between 0.75°C and 0.99°C) higher than the average over the 1850–1900 period (very high confidence). Estimated anthropogenic global warming matches the level of observed warming to within $\pm 20\%$ (likely range). Estimated anthropogenic global warming is currently increasing at 0.2°C (likely between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (high confidence). (IPCC, 2018)

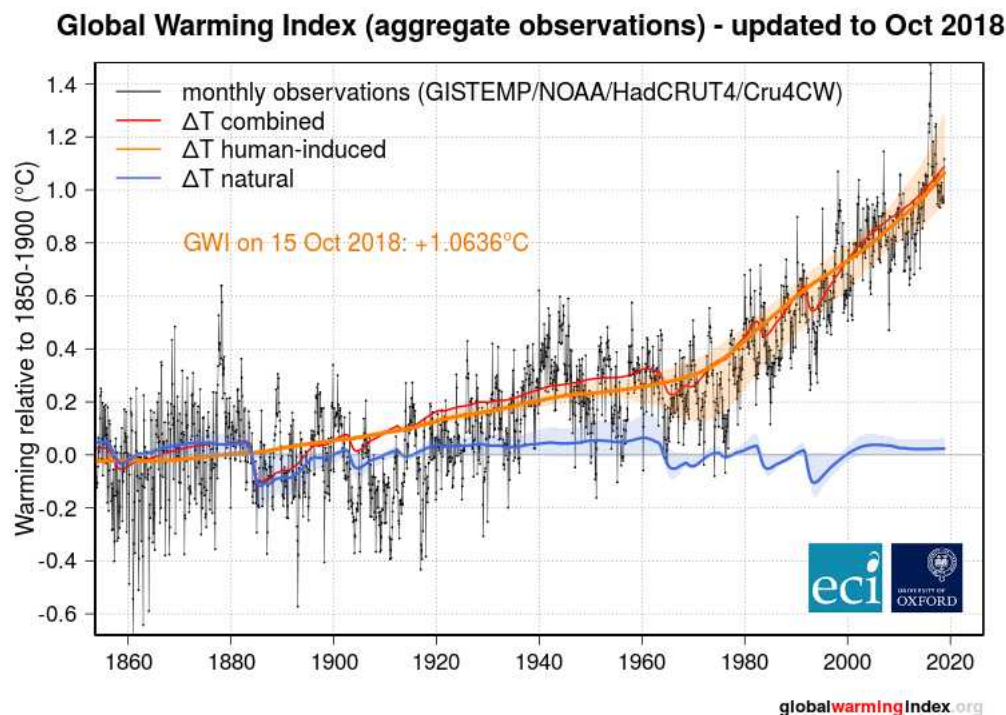


Figure 3: Global warming index – warming levels Oct 2018 1.06°C Source: globalwarmingindex.org

Human-induced warming reached approximately 1°C (*likely* between 0.8°C and 1.2°C) above pre-industrial levels in 2017 (high confidence) (Allen et al., 2018). The global temperature increase is an average across the world. Research has shown that the warming above land is generally higher than above the ocean. Additionally, specific regions and seasons experience a higher warming with the Arctic reaching two to three times higher temperatures than the average (high confidence) (IPCC, 2018).

Today, 20-40% (depending on data source) of the world population has already experienced more than 1.5° warming in at least one season in the decade 2006-2015.

Past emissions are unlikely to raise temperatures above 1.5°C above pre-industrial levels (medium confidence). Based on current emissions, 1.5°C warming will likely be reached between 2030 and 2052 (IPCC, 2018). Based on the Climate Action Tracker information 2°C warmer world would be reached in about 2055 (median) and a 3°C towards 2100 (median) (Climate Action Tracker, 2018).

3.3. Sea Level Rise globally

Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (high confidence). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-meter rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5°C to 2°C of global warming (medium confidence).

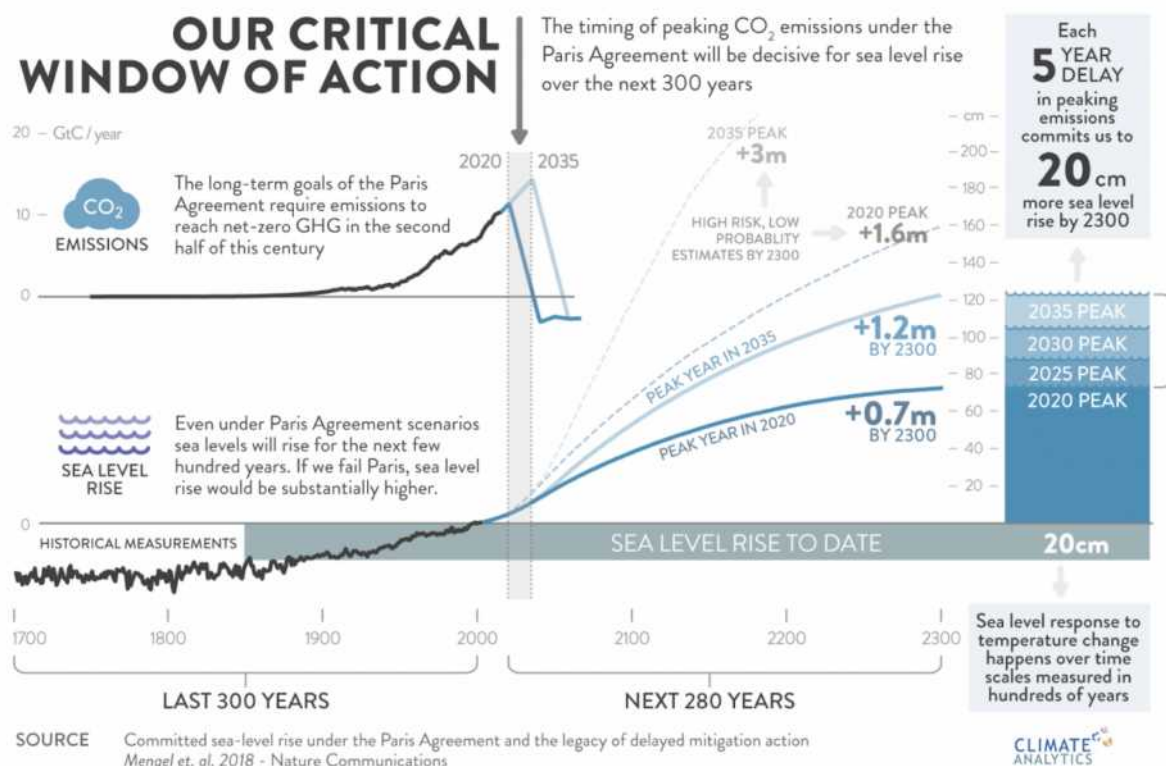


Figure 4: Our critical window of action. Source: (Mengel et al., 2018b)

Currently the world has experienced about 20 cm of global sea level rise since pre-industrial times.

The IPCC states with high confidence that the sea level will continue to rise well beyond 2100, and the magnitude and rate of this rise will depend on future emission pathways. For 1.5°C the IPCC report projects a sea level rise of up to 0.77m by 2100 (Ove Hoegh-Guldberg, Jacob, Taylor, & et al, 2018) for scenarios not exceeding 2°C. Sea levels could be much higher, for higher warming scenarios (Nauels et al., 2017).

The paper from Mengel et al. 2018 analyses the relationship between future emission pathways and sea level rise. As Figure 4 shows the timing of mitigation actions matters for long-term sea level rise. Every 5-year delay in limiting CO₂ emissions will increase the sea level rise in 2300 by 20 cm. This analysis was only done for 1.5°C emission pathway (RCP2.6). For higher emission scenarios, reaching 2°, 3° or even 4°C higher levels of sea level rise can be expected. Future generations will therefore be affected by actions taken within the next decades (Mengel et al., 2018a). A reduction of 10 cm in global sea level rise would translate into 10 million fewer people exposed based on the population of 2010 (high confidence). Particularly Small Island Developing States (SIDS), low-lying coastal areas and deltas are at risk of increased flooding and loss of land due to sea level rise. A slower rate of sea level rise will enable these regions with a greater opportunity for adaptation (medium confidence). These regions have an increasing risk of experiencing saltwater intrusion, flooding and damage to infrastructure (high confidence) (Ove Hoegh-Guldberg et al., 2018).

Furthermore, the oceans have been absorbing about 30% of the past CO₂ emissions which has led to ocean acidification and changes to the carbonate chemistry (high confidence) impacting marine organisms and ecosystems. There is also *high confidence* that global warming has resulted in an increase in the frequency and duration of marine heatwaves (IPCC, 2018).

Considering that cold regions are warming more rapidly , by a factor of 2-3 times , the Arctic is likely to experience a warming of up to 4.5°, associated with a global increase of 1.5°C (high confidence). For a 2° warmer world Arctic temperatures would be expected to go up to 8°C (high confidence). Landscapes such as the tundra would shift northwards. Permafrost would likely deteriorate (IPCC, 2018).

Instabilities for both the Greenland and the Antarctic ice sheets exist, which could result in a multi- measure sea level rise. These instabilities are less likely to be triggered at a lower warming level (1.5°C) than higher ones (medium confidence). The Arctic sea ice is likely to be maintained under the 1.5°C scenario. For 1.5 to 2° warming, scientists expect every second summer to be ice-free. For 2 to 3°C, the Arctic is very likely ice free in summer. Polar bears, whales, seals and sea birds would lose their natural habitat (IPCC, 2018).

The impacts that climate change has on the ocean system go beyond the impacts felt in the Arctic region and include erosion of land, loss of land, loss of mangroves and loss of coral reefs. The following figure (5) shows the expected impact of different warming levels on different natural and human systems and the respective confidence level.

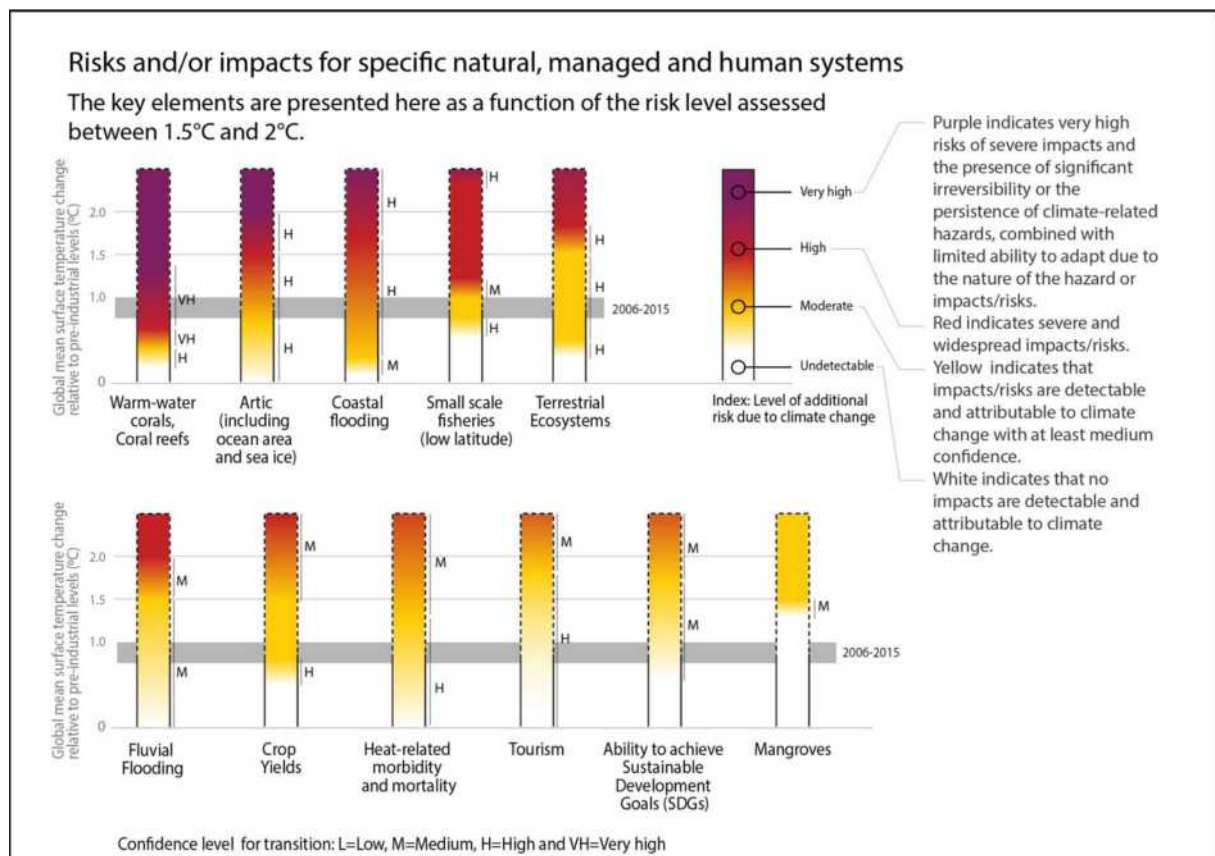


Figure 5: Risks and/or impacts for specific natural, managed and human systems. Source: Ove Hoegh-Guldberg et al., 2018

3.4. Intensity of weather events

Evidence from attributed changes in some climate and weather extremes for a global warming of about 0.5°C supports the assessment that an additional 0.5°C of warming compared to present is associated with further detectable changes in these extremes (medium confidence). Several regional changes in climate are assessed to occur with global warming up to 1.5°C compared to pre-industrial levels, including warming of extreme temperatures in many regions (high confidence), increases in frequency, intensity, and/or amount of heavy precipitation in several regions (high confidence), and an increase in intensity or frequency of droughts in some regions (medium confidence) (IPCC, 2018).

Extreme weather events are among the most prominent impacts of climate change. Many extreme weather events including heat waves, extreme precipitation, tropical cyclones, drought and associated wildfires, and flooding have already increased in frequency and intensity due to observed climate change and will continue to do so with increasing warming. An increasing number of extreme events can be attributed in part to climate change (see figure 6).

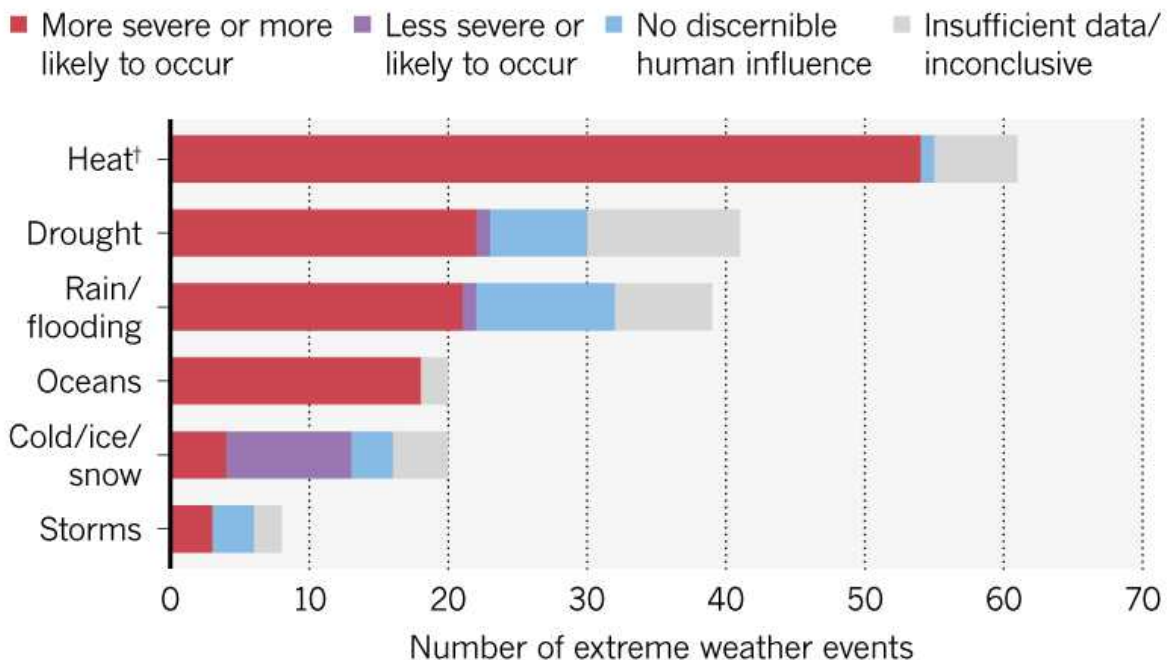
Heat waves

Regarding hot extremes, the strongest warming is expected to occur at mid-latitudes in the warm season (with increases of up to 3°C for 1.5°C of global warming, i.e., a factor of two) and at high latitudes in the cold season (with increases of up to 4.5°C at 1.5°C of global warming, i.e., a factor of three) (high confidence). The strongest warming of hot extremes is projected to occur in central and eastern North America, central and southern Europe, the Mediterranean region (including southern Europe, northern Africa and the Near East), western and central Asia, and southern Africa (medium confidence). The number of exceptionally hot days are expected to increase the most in the tropics, where interannual temperature variability is lowest; extreme heatwaves are thus projected to emerge earliest in these regions, and they are expected to already become widespread there at 1.5°C global warming (high confidence). (Ove Hoegh-Guldberg et al., 2018)

Attribution studies show that extreme heat experienced today can already be associated with anthropogenic climate change. Particularly for heat related studies, scientists were able to show that due to human-induced climate change heat related events are more severe or more likely to occur.

Attribution science

Researchers have published more than 170 studies* examining the role of human-induced climate change in 190 extreme weather events.



©nature

*Studies from 2004–18 collated by *Nature* and CarbonBrief. †Heat includes heatwaves and wildfires; Oceans includes studies on marine heat, coral bleaching and marine-ecosystem disruption.

Figure 6: Studies in attribution of human-induced climate change and extreme weather events. Source: Schiermeier, 2018

Studies by King & Karoly (2017) show the increasing likelihood of similar heatwave events occurring with current temperature increase of about 1°C, for 1.5 and 2° warming in

comparison to a world without climate change. When looking at the 2003 heat wave in central Europe this would be a once in 100 years event without climate change. At current warming levels a similar event can be expected once every four years. For 1.5°C warming the likelihood increases to 4 out of 10 summers and for 2°C warming reaches 6 out of 10.

For the 2018 north hemispheric concurrent heat events, attribution to climate change even goes further. Vogel et al. (2019) found that these events would not have occurred without human- induced climate change and that these events would be exceeded in severity or frequency annually under 2°C warming.

—— Likelihood of similar event per year ——

EVENT	CONTEXT, IMPACT	VARIABLE	NATURAL	CURRENT	1.5°C	2°C
Europe 2016	Hottest year on record	T	0% (0%)	27% (17-37%)	52% (42-63%)	88% (83-92%)
Central England 2014	Hottest year on record	T	0% (0-1%)	19% (13-25%)	29% (21-37%)	48% (38-59%)
Central Europe JJA 2003	Hottest summer on record, thousands of heat-related deaths	T	1% (1-2%)	25% (17-33%)	42% (32-51%)	59% (50-70%)
		TXx	2% (0-6%)	21% (7-37%)	21% (9-34%)	31% (14-50%)

Figure 7: Likelihood of similar heat waves occurring without climate change, at current warming levels, for 1.5° and 2° warming. Source: King & Karoly, 2017

According Chapter 3 of the IPCC 1.5 Special Report limiting global warming to 1.5°C means that 420 million fewer people will be exposed to extreme heatwaves and 65 million less are exposed to exceptional heatwaves (medium confidence). The report also points out that twice as many megacities will be exposed to heat stress at 1.5°C warming in comparison to present day warming levels exposing up to 250 million additional people to deadly heat wave conditions by 2050 (Roy et al., 2018).

Drought

The frequency and intensity of droughts has already increased in some regions, including the Mediterranean, west Asia, many parts of South America, much of Africa, and north-eastern Asia (IPCC, 2019b). The risk of extreme drought is substantially higher for 2°C warming levels and above than for 1.5°C global warming (medium confidence). The Mediterranean region and southern Africa particularly will be affected by extreme drought including increasing water stress (Ove Hoegh-Guldberg et al., 2018).

The IPCC report offers a detailed analysis for the Eastern Mediterranean region showing that the drought episode between 2007-2010 was the longest and most intense one in 900 years. A comparison between the 2008 drought and the drought in 1960 for Syria which was similar in precipitation, but with lower temperatures than 2008, shows that the increased evapotranspiration due to higher temperatures and the increase in population (from 5 to 22 million) amplified the drought in 2008 (Ove Hoegh-Guldberg et al., 2018).

Extreme precipitation

There is medium confidence that extreme precipitation events have increased in frequency, intensity and/or amount of heavy precipitation due to anthropogenic climate change on a global level which affect all sectors including agriculture, transport, health, freshwater availability, biodiversity, forests, etc. Heavy precipitation (aggregated at a global scale) is projected to increase with higher temperatures (IPCC, 2018). The largest increase in heavy precipitation is expected in high-latitude regions (e.g. Alaska /western Canada, eastern Canada/ Greenland/Iceland, northern Europe and northern Asia); mountainous regions (e.g., Tibetan Plateau); eastern Asia (including China and Japan); and eastern North America (medium confidence). Heavy precipitation associated with tropical cyclones will increase with higher temperatures (e.g. 2°C instead of 1.5°C of global warming).

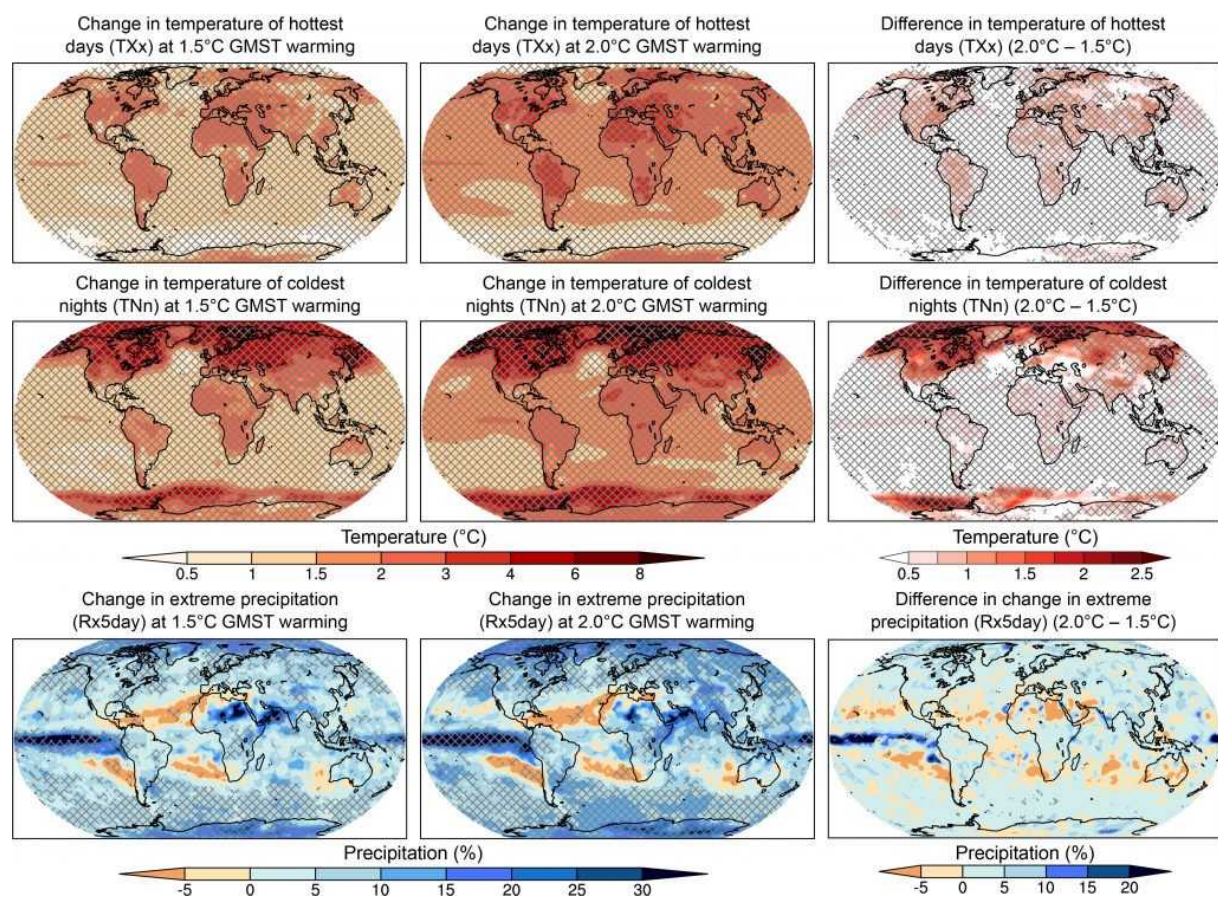


Figure 8: Projected changes in extremes at 1.5°C (left) and 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of global warming (right). Source: Ove Hoegh-Guldberg et al., 2018

Figure 8 from the IPCC 1.5 special report shows the global increase in extreme precipitation for the world (bottom left and middle for 1.5°C and 2°C warming respectively). The bottom right graph shows the difference in change between 2°C and 1.5°C warming. The top six maps show the change in temperature extreme for hottest days and coldest nights.

Floods

According to the IPCC 1.5 special report, the expected frequency and magnitude of floods are likely higher for temperatures exceeding 1.5°C warming (medium confidence). At 1.5°C global warming the IPCC 1.5 special report gives medium confidence for an expansion of the areas

with significant increases in runoff and areas affected by flood hazards. For 2°C further increase in runoff and flood hazards is expected (medium confidence) (Ove Hoegh-Guldberg et al., 2018).

Tropical cyclones

While tropical cyclones are projected to decrease in frequency they will increase in the number of very intense cyclone (limited evidence, low confidence). Major tropical cyclones develop at sea surface temperatures of 27°C and above. With increasing global temperatures, sea surface temperatures also increase making Cat. 3-5 tropical cyclones more probable (Ove Hoegh-Guldberg et al., 2018). The following graphic supports the shift towards an increase of Cat. 3-5 cyclones both in the Caribbean and the Pacific region.

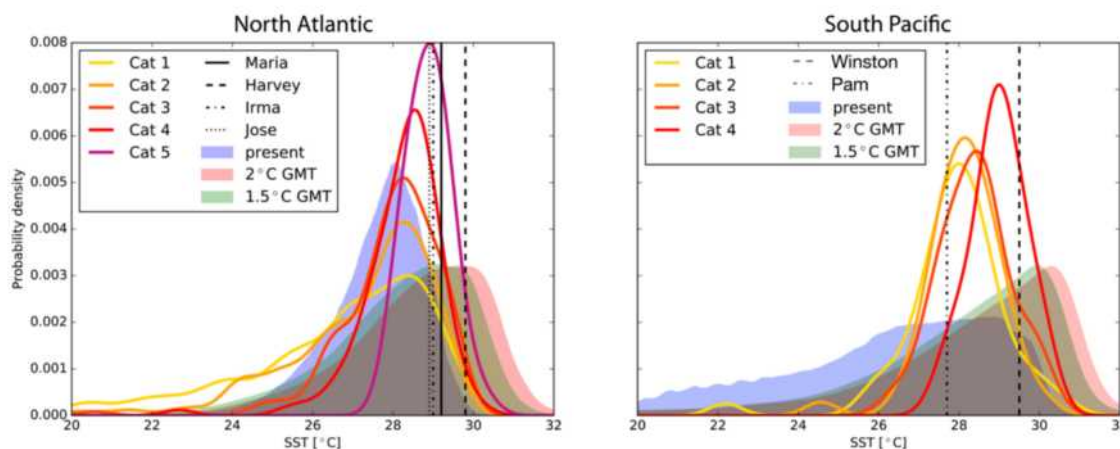


Figure 9: Probability density of tropical cyclone formation against sea surface temperatures (SST) in the formation region by cyclone category for the North Atlantic (left) and the South Pacific basin (right). Black lines show recent tropical cyclones. The shaded areas show monthly sea-surface temperature (SST) distributions for the months of the main cyclone season including all grid cells of the main development region. Present (blue) for the period 1986-2005. Projections for 2°C global warming (red) and 1.5°C global warming (green) are presented for a multi-model mean of CMIP5 models. Source: Thomas, Pringle, Pfeleiderer, & Schleussner, 2017

Tropical cyclones are often linked to extreme precipitation and extreme sea level rise which creates a compound climate hazard (Ove Hoegh-Guldberg et al., 2018).

A recent study on wave-driven flooding shows that most atolls located in the tropics will be uninhabitable by 2050 due to expected annual wave overwash which will contaminate available freshwater resources without allowing them to recover and will damage the infrastructure of these islands (Storlazzi et al., 2018).

Wildfires

Due to increasing droughts and heat waves, wildfires are increasing in intensity. The Mediterranean in particular will experience an increase under 1.5°C warming. Under 2°C warming, the USA and Canada are projected to experience increasing wildfires. According to the IPCC 1.5 special report, there is still little information available for many world regions including Central and South America, Australia, Russia, China, and Africa (Ove Hoegh-Guldberg et al., 2018). The IPCC 5th Assessment Report rates with medium confidence that the frequency of wildfires in subarctic conifer forests and tundra will increase (Field et al., 2014).

3.5. Impacts on different sectors

The global climate has changed relative to the pre-industrial period, and there are multiple lines of evidence that these changes have had impacts on organisms and ecosystems, as well as on human systems and well-being (high confidence) (Ove Hoegh-Guldberg et al., 2018).

The IPCC 5th Assessment Report gives an overview of key sectors that are already impacted by climate change in different regions.

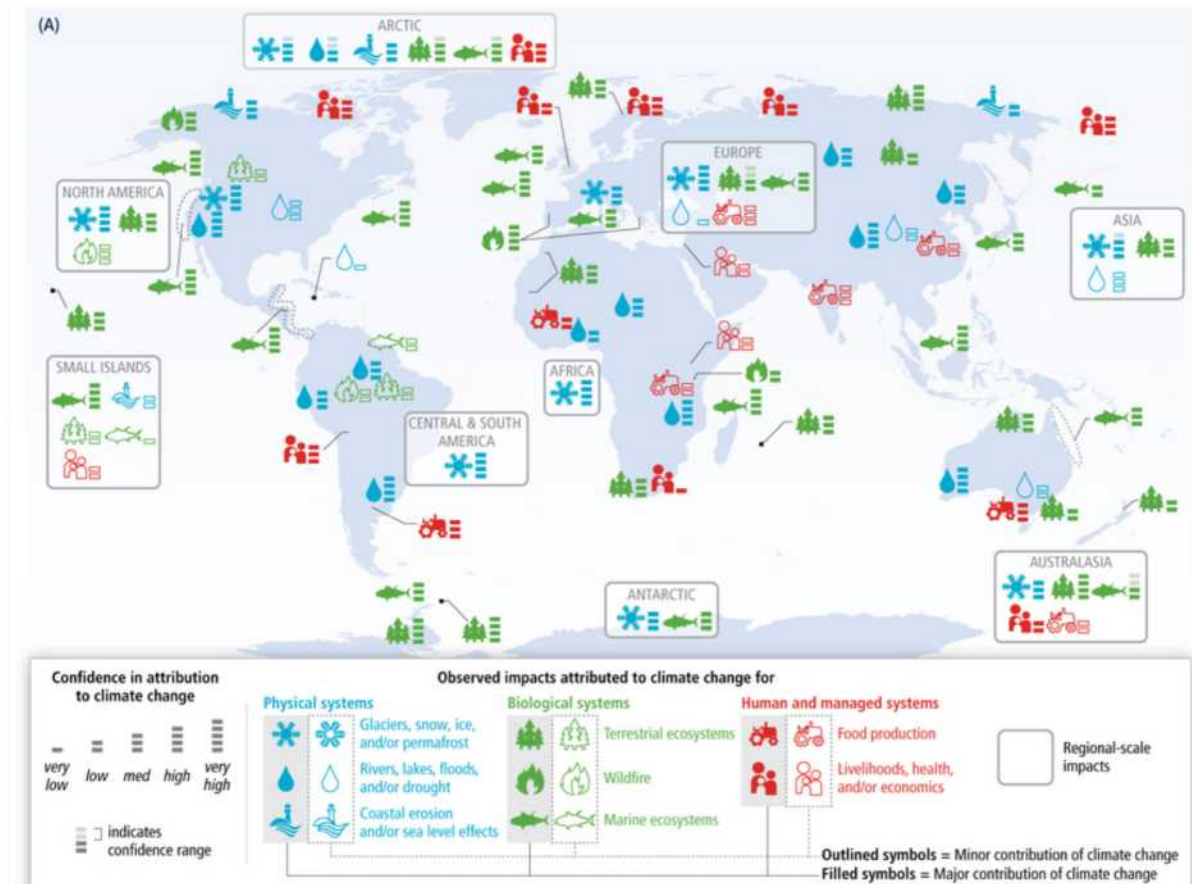


Figure 10: Widespread impacts in a changing world. Global patterns of impacts in recent decades attributed to climate change, based on studies since the AR4. Impacts are shown at a range of geographic scales. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact, and confidence in attribution. Source: C B Field et al., 2014

The newly published special report on climate change and land assesses the risk to humans and ecosystems from changes in land-based processes as a result of climate change and is able to show that today at 1°C warming impacts are noticeable and will increase significantly for 1.5°C, 2°C and further degrees of warming. Food supply insecurity in particular could affect whole regions periodically (medium confidence) (IPCC, 2019b).

A. Risks to humans and ecosystems from changes in land-based processes as a result of climate change

Increases in global mean surface temperature (GMST), relative to pre-industrial levels, affect processes involved in desertification (water scarcity), land degradation (soil erosion, vegetation loss, wildfire, permafrost thaw) and food security (crop yield and food supply instabilities). Changes in these processes drive risks to food systems, livelihoods, infrastructure, the value of land, and human and ecosystem health. Changes in one process (e.g. wildfire or water scarcity) may result in compound risks. Risks are location-specific and differ by region.

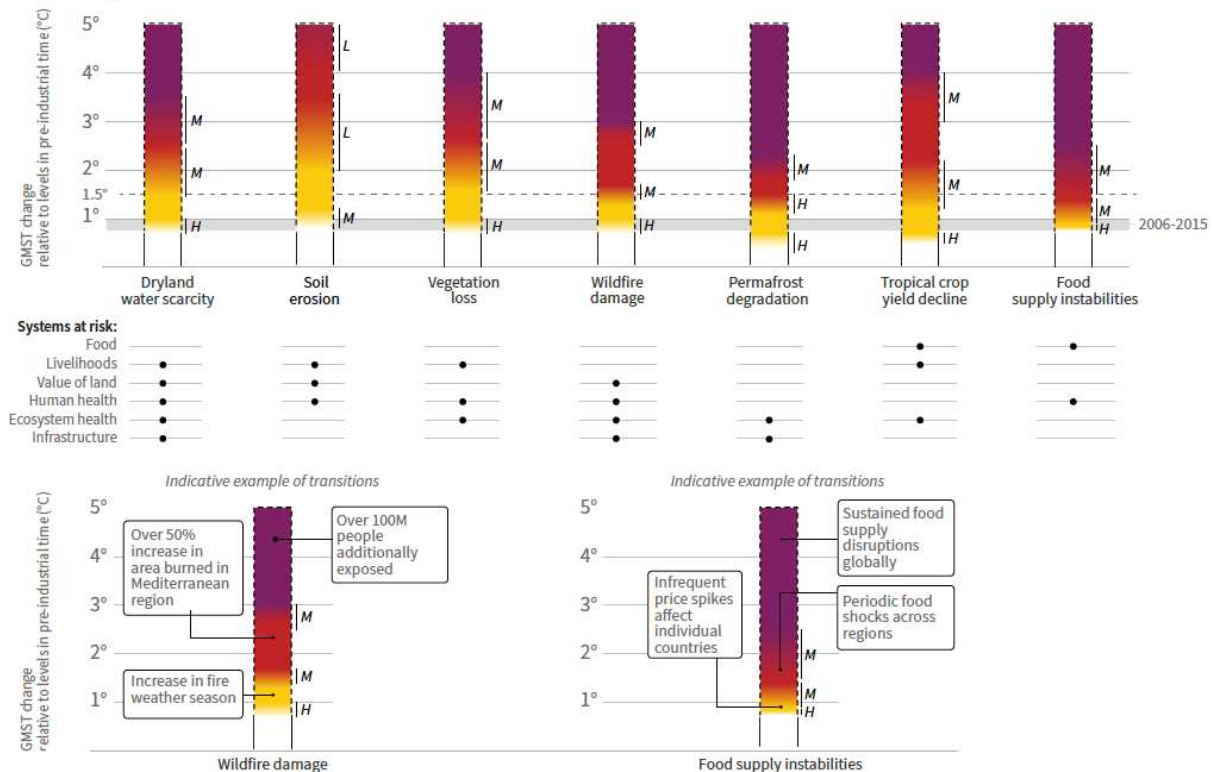


Figure 11: Risks to land-related human systems and ecosystems from global climate change, socio-economic development and mitigation choices in terrestrial ecosystems. Source: IPCC, 2019

3.5.1. Crops

Climate change impacts on crop yields have been detected and attributed to climate change with *high confidence*. Today crop production has been affected by climate change impacting particularly local crops that grow under specific climate conditions, such as for example olives or grapevines in Mediterranean. Among the main agricultural crops worldwide, particularly wheat and maize have experienced the highest negative impact. While some high-altitude areas experience an increase in crop yield; tropical crop yield in West Africa, Southeast Asia and Central and South America in particular are at a significant risk of declining for a global temperature increase of 2° and more (high confidence). West Africa has been identified as a hotspot for negative impacts from climate change on crop yields and production for 2° warming endangering food security in the future (Ove Hoegh-Guldberg et al., 2018).

For each degree of global mean temperature increase, a significant reduction in global production of all main agricultural crops is projected. Reductions in global production are projected to be as follows: wheat (by $6.0 \pm 2.9\%$), rice (by $3.2 \pm 3.7\%$), maize (by $7.4 \pm 4.5\%$), and soybean (by 3.1%). Adaptation measures such as adjusted planting times, fertilizers and irrigation may increase wheat and maize yields by 7-12% (de Coninck et al., 2018).

Heat stress impacts livestock causing increased animal mortality, increased water need and reduced production of e.g. milk. At approximately 2°C of warming a global loss of 7–10% of rangeland livestock is projected, with considerable economic consequences for many communities and regions (medium confidence) (Ove Hoegh-Guldberg et al., 2018).

3.5.2. Freshwater availability

Water scarcity has been an increasing problem which has worsened due to changes in climate, water consumption behavior, population growth and distribution, ranging from .24 billion (14% of the global population) in the 1900s, to 3.8 billion (58%) in the 2000s. 1.1 billion people (17% of the global population) mostly in South and East Asia, North Africa and the Middle East faced serious water shortage and high water stress in the 2000s (Ove Hoegh-Guldberg et al., 2018).

Even though regions particularly affected by drought will face an increasing impact on the level of water stress, the IPCC 1.5 special report concludes that the changes in population will generally have a greater effect on water resource availability. At 1.5°C warming the percentage of the world population expected to be exposed to water stress will increase by 4%, while 8% more - will be exposed at 2°C warming (Roy et al., 2018).

Small islands in particular will face water stress linked to coastal flooding and sea level rise which is expected to be worse at 2°C in comparison to 1.5° warming (medium confidence) (Ove Hoegh-Guldberg et al., 2018).

3.5.3. Biodiversity/ecosystems

The IPCC 1.5 special report confirms the findings of IPCC 5th Assessment Report which concluded that the geographical ranges of many terrestrial and freshwater plant and animal species have moved over the last several decades in response to warming: approximately 17 km poleward and 11 m up in altitude per decade (Ove Hoegh-Guldberg et al., 2018).

Of 105,000 species studied, 6% of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5°C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C (medium confidence). Impacts associated with other biodiversity-related risks such as forest fires and the spread of invasive species are lower at 1.5°C compared to 2°C of global warming (high confidence) (IPCC, 2018).

Alpine regions are generally regarded as climate change hotspots given that rich biodiversity has evolved in their cold and harsh climate, but with many species consequently being vulnerable to increases in temperature. Under regional warming, alpine species have been found to migrate upwards on mountain slopes (Reasoner and Tinner, 2009), an adaptation response that is obviously limited by mountain height and habitability (Ove Hoegh-Guldberg et al., 2018).

3.5.4. Forests

Forests, particularly tropical forests are considered the biggest carbon sink and afforestation and reforestation are part of mitigation strategies to store carbon.

Projected impacts on forests as climate change occurs include increases in the intensity of storms, wildfires and pest outbreaks (Settele et al., 2014), potentially leading to forest dieback (medium confidence). Warmer and drier conditions in particular facilitate fire, drought and insect disturbances, while warmer and wetter conditions increase disturbances from wind and pathogens (Seidl et al., 2017). Particularly vulnerable regions are Central and South America, Mediterranean Basin, South Africa, South Australia where the drought risk will increase (Ove Hoegh-Guldberg et al., 2018).

The increase in frequency of forest fires in North America between 1984-2015 has been attributed to climate change. Compared to what would have been expected without climate change, forest fires via the mechanism of increasing fuel aridity almost doubled in the western USA (Ove Hoegh-Guldberg et al., 2018).

High-latitude tundra and boreal forest are particularly at risk, and woody shrubs are already encroaching into tundra (*high confidence*) and will proceed with further warming. Increased disturbance from fire, pests and heat-related mortality may affect the southern boundary of boreal forests in particular (*medium confidence*) (Ove Hoegh-Guldberg et al., 2018).

At 1.5°C warming levels, deforestation and fire increases pose an uncertain risk to forest dieback. At 2- 3°C warming levels, a reduced extent of tropical rainforest is expected for Central America, where the tropical rainforest biomass would be reduced by about 40% under global warming of 3°C, with considerable replacement by savanna and grassland. With a global warming of close to 1.5°C in 2050, a biomass decrease of 20% is projected for tropical rainforests of Central America. If a linear response is assumed, this decrease may reach 30% (medium confidence) (Ove Hoegh-Guldberg et al., 2018).

3.5.5 Land degradation, permafrost and biomes

Climate change exacerbates land degradation, particularly in low-lying coastal areas, river deltas, drylands and in permafrost areas (high confidence). People living in already degraded or desertified areas are increasingly negatively affected by climate change (high confidence) (IPCC, 2019b).

Land degradation resulting from the combination of sea level rise and more intense cyclones is projected to jeopardize lives and livelihoods in cyclone prone areas (very high confidence). Within populations, women, the very young, elderly and poor are most at risk (high confidence) (IPCC, 2019b).

Climate change can lead to land degradation, even with the implementation of measures intended to avoid, reduce or reverse land degradation (high confidence). Examples of climate

change induced land degradation that may exceed limits to adaptation include coastal erosion exacerbated by sea level rise where land disappears (high confidence), thawing of permafrost affecting infrastructure and livelihoods (medium confidence), and extreme soil erosion causing loss of productive capacity (medium confidence) (IPCC, 2019b).

The Arctic tundra biome is experiencing increasing fire disturbance and permafrost degradation (Ove Hoegh-Guldberg et al., 2018).

At a 1.5°C warming scenario, a biome shift in the tundra and permafrost deterioration are likely. A 17-44% reduction in permafrost is projected for under 1.5°C warming, compared to 28-53% for under 2°C warming. For more than 2°C warming there is potential for permafrost to collapse (low confidence). In any case, the reduction of permafrost will cause an irreversible loss of stored carbon (Ove Hoegh-Guldberg et al., 2018).

The map shows the results of an ecosystem model illustrating that biome shifts in the Arctic, Tibet, Himalayas, southern Africa and Australia would be avoided by constraining warming to 1.5°C compared with 2°C (Ove Hoegh-Guldberg et al., 2018).

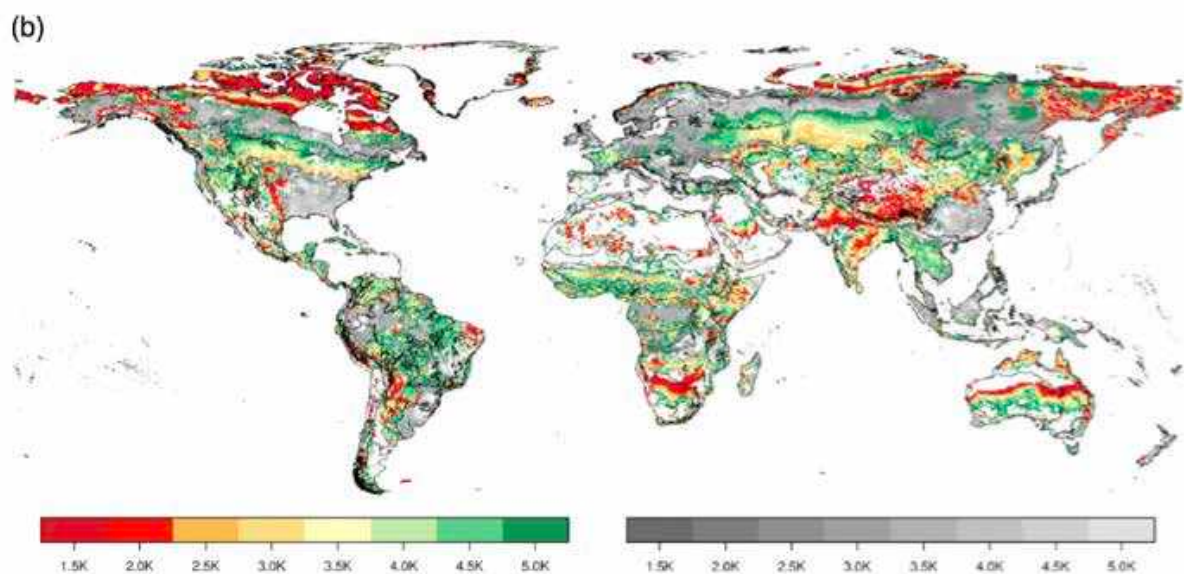


Figure 12: Level of global temperature anomaly above pre-industrial levels that leads to significant local changes in terrestrial ecosystems. Regions with severe (coloured) or moderate (greyish) ecosystem transformation; delineation refers to the 90 biogeographic regions. All values denote changes found in >50% of the simulations. Source: (Gerten et al., 2013). Regions coloured in dark red are projected to undergo severe transformation under a global warming of 1.5°C while those coloured in light red do so at 2°C; other colours are used when there is no severe transformation unless global warming exceeds 2°C. Source: Ove Hoegh-Guldberg et al., 2018

3.5.6. Economic impacts

Global economic damages of climate change are projected to be smaller under warming of 1.5°C than 2°C in 2100. The mean net present value of the costs of damages from warming in 2100 for 1.5°C and 2°C (including costs associated with climate change-induced market and non-market impacts, impacts due to sea level rise, and impacts associated with large-scale

discontinuities) are \$54 and \$69 trillion, respectively, relative to 1961–1990 (Ove Hoegh-Guldberg et al., 2018).

As almost all impacts will worsen with increasing temperatures, the costs associated with these impacts will increase as well. At the same time, extreme events and slow-onset events as well as related health impacts such as heat stress will decrease the GDP. The IPCC 1.5 special report states that at 2°C global warming, lower economic growth is projected for many countries than at 1.5°C of global warming, with low-income countries projected to experience the greatest losses (low to medium confidence) (Ove Hoegh-Guldberg et al., 2018). A recent paper from Burke et al. (2018) shows decreases of global GDP for different warming levels between 10 and more than 30% for 1.6 and 4.3° warming levels by 2100 respectively (RCP2.6 and RCP8.5).

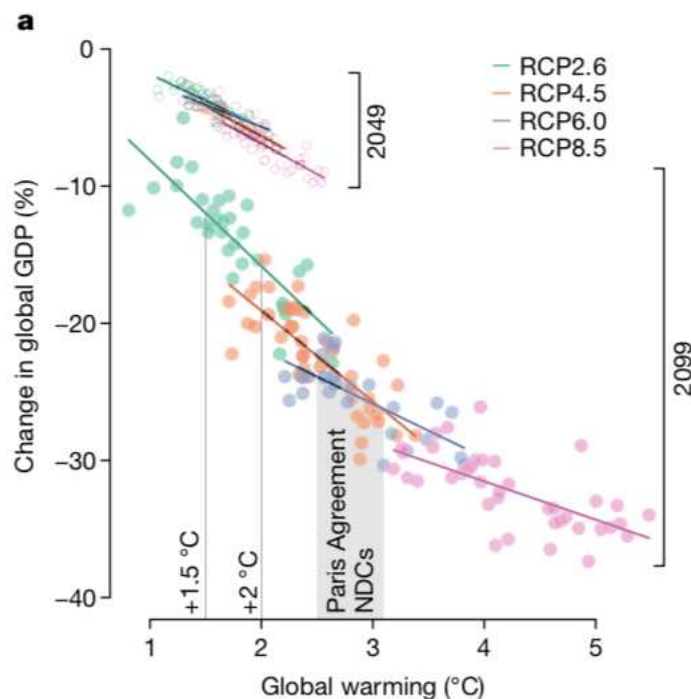


Figure 13: The impact of global warming on global GDP per capita, relative to a world without warming, for different forcing levels. Projected percentage change in global GDP for different climate models under different warming levels (RCPs), relative to a no-warming baseline. Colours denote different warming levels. Green about 1.6°C warming by 2100, orange about 2.3°C warming by 2100, purple 2.8°C warming by 2100 and pink 4.3°C warming by 2100. Warming is relative to pre-industrial levels. Unfilled points show mid-century projections, filled points show end-of-century projections. Vertical lines show the UN temperature targets as well as the range of estimates of end-of-century warming under current Paris commitments.

3.6. Health

The IPCC 5th Assessment Report concluded there is high to very high confidence that climate change will lead to greater risks of injuries, disease and death, owing to more intense heatwaves and fires, increased risks of undernutrition, and consequences of reduced labour productivity in vulnerable populations (Ove Hoegh-Guldberg et al., 2018).

In every crisis, children are amongst the most vulnerable. The same is true for climate change. Considering that areas at risk for flood and drought often overlap with areas of higher poverty, the most disadvantaged will be unproportionally affected by climate change (UNICEF, 2015). This definition is in line with the one of the IPCC 1.5 special report which defines the population at highest risk to include older adults, children, women, those with chronic diseases, and people taking certain medications (*very high confidence*) (Ove Hoegh-Guldberg et al., 2018).

These effects will impact children more significantly than adults, as they do not only face direct risks of climate change, but are also affected indirectly for example if their parents lose their livelihood or are affected by crop failure (UNICEF, 2015). Additionally and compared to adults, children are physically more vulnerable to the direct effects of extreme heat, drought, and natural disasters (Currie & Deschênes, 2016). The following overview shows the health impacts children face due to the diverse environmental impacts of climate change.

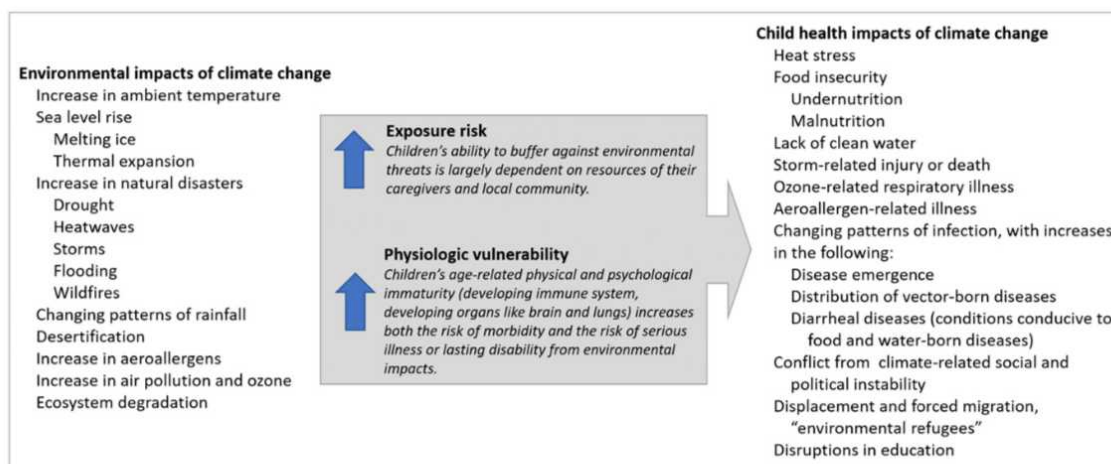


Figure 14: Climate-related environmental health threats to children. Source: Pass Philipsborn & Chan, 2018

3.6.1. Health impacts linked to temperature rise

Any increase in global temperature (e.g., +0.5°C) is projected to affect human health, with primarily negative consequences (high confidence) (Ove Hoegh-Guldberg et al., 2018).

Higher temperature increase will have a negative effect on heat-related morbidity and mortality (*very high confidence*), and for ozone related mortality (*high confidence*). Urban populations in particular will be affected by amplified impacts due to urban heat islands (*high confidence*) (Ove Hoegh-Guldberg et al., 2018). The extent that urban populations are at risk of being impacted negatively by climate change depends on human vulnerability and the effectiveness of adaptation for regions (coastal and non-coastal), informal settlements and infrastructure sectors (such as energy, water and transport) (*high confidence*) (Ove Hoegh-Guldberg et al., 2018).

Additionally, poverty and disadvantage have increased with recent warming (about 1°C) and are expected to increase for many populations as average global temperatures increase from 1°C to 1.5°C and higher (medium confidence) (Ove Hoegh-Guldberg et al., 2018).

3.6.2. Health impacts linked to extreme weather events

Due to several major global trends, including demographic and migration trends, more and more people are living in disaster-prone areas and exposed to weather extremes (UNICEF, 2015).

According to the report from UNICEF (2015) 500 million children live in extremely high flood occurrence zones and 160 million live in high or extremely high drought severity zones. With an expected increase in the frequency and intensity of these events driven by climate change, children will face even greater risk of exposure in the future. Infrastructure such as schools, hospitals and transport, as well as natural goods such as water systems and crops are crucial for the well-being of children and can get destroyed or damaged during floods and droughts.

Mortality

Studies have shown that children under 12 months old are particularly vulnerable to heatwaves. The mortality rate of infants and small children who are more likely to die or suffer from heatstroke because they are unable or lack agency to regulate their body temperature and control their surrounding environment. Dehydration can be caused by extreme heat stress which slows the sweating rate leading to hyperthermia and infant mortality. Diarrhea is another factor that can increase the risk of heat injury and death (UNICEF, 2015).

Physical impacts

The long-term effects of experiencing flooding can be substantial for children and has not only psychological impacts but results in physical impacts as well. A long-term study on children exposed to El Niño flooding in 1997/98 showed that five years later they were found to be smaller (1-1.8cm shorter than their peers), had higher incidence of stunting and lower body weight for age (0.38kg) compared to the control group (UNICEF, 2015).

Heatwaves can cause heat rash, heat-related cramps, exhaustion and stroke particularly in young children. Children with chronic health conditions, those living in poverty, those who lack adequate nutrition, water and sanitation face a higher risk (UNICEF, 2015).

Psychological impacts

Extreme events can cause emotional distress for children including fear of separation from their families, mounting tensions and pressures within households, a lack of emotional support at family level, and increased workloads (UNICEF, 2015).

A study conducted in southeast USA following Hurricane Andrew and another study in Poland conducted after the 1997 floods showed that children are 2-3 times more likely to suffer from posttraumatic stress disorder (UNICEF, 2015).

Other health impacts

Potential wildfires resulting from extreme heat and drought can cause death and displacement or destruction or damage of essential services, shelter and food (UNICEF, 2015).

3.6.3. Food security

An estimated 821 million people are currently undernourished, 151 million children under 5 are stunted, 613 million women and girls aged 15 to 49 suffer from iron deficiency, and 2 billion adults are overweight or obese. The food system is under pressure from non-climate stressors (e.g., population and income growth, demand for animal-sourced products), and from climate change. These climate and non-climate stresses are impacting the four pillars of food security (availability, access, utilization, and stability) (IPCC, 2019a).

Climate change has already affected food security due to warming, changing precipitation patterns, and greater frequency of some extreme events (high confidence) (IPCC, 2019b). The people most affected live in low and middle-income countries some of which already at present day face a decline in food security partly due to migration and poverty (Allen et al., 2018).

Although hunger has been declining for the past 3 decades, undernutrition has worsened, particularly in parts of sub-Saharan Africa, South-Eastern Asia and Western Asia, and recently Latin America. Deteriorations have been observed most notably in situations of conflict and conflict combined with droughts or floods (IPCC, 2019a). The stability of food supply is projected to decrease as the magnitude and frequency of extreme weather events that disrupt food chains increases (high confidence). Increased atmospheric CO₂ levels can also lower the nutritional quality of crops (high confidence) (IPCC, 2019a).

Overall, food security is expected to be reduced at 2°C global warming compared to 1.5°C, owing to projected impacts of climate change and extreme weather on yields, crop nutrient content, livestock, fisheries and aquaculture and land use (cover type and management) (high confidence) (Ove Hoegh-Guldberg et al., 2018). The West Sahel zone is projected to face serious food security issues above 2°C (Ove Hoegh-Guldberg et al., 2018).

Considering that children need to consume more food and water per unit of body weight than adults, they are more vulnerable to deprivation of food and water. Therefore, undernutrition affects children over-proportionally and is responsible for nearly half of all under-five deaths. Extreme events such as droughts increase the direct risk of undernutrition, but also impacts children indirectly. The weight of children born to women exposed to drought in the year before giving birth can be negatively impacted. Furthermore, exposure to undernutrition in their first two years of life can cause stunting in children which affects physical and cognitive development, impacting the rest of a child's life – including his or her schooling, health and livelihood (UNICEF, 2015).

3.6.4. Spreading of diseases

Changing weather patterns are associated with shifts in the geographic range, seasonality and transmission intensity of selected climate-sensitive infectious diseases (Ove Hoegh-Guldberg et al., 2018).

Vector-borne diseases

Children face a higher vulnerability to vector-borne diseases such as dengue and malaria (UNICEF, 2015). The World Health Organization (WHO) has estimated that 88 % of the existing burden of disease as a result of climate change occurs in children under five years of age (Ahdoot & Pacheco, 2015). Malaria is estimated to be responsible for 438,000 deaths in 2015 of which two-thirds were children below the age of five (UNICEF, 2015).

Risks for some vector-borne diseases, such as malaria and dengue fever are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*). Overall for vector-borne diseases, whether projections are positive or negative depends on the disease, region and extent of change (*high confidence*) (Ove Hoegh-Guldberg et al., 2018).

Water-borne diseases

Diarrheal diseases are estimated to have caused 480,000 deaths of children in 2016 alone (United Nations Children's Fund, 2018). They rank among the top five causes of death for children under five. Extreme events such as floods, droughts and severe storms which are increasing in frequency and intensity due to climate change, disrupt the access to safe water and sanitation which can lead to contamination of water resources resulting in water-borne diseases (UNICEF, 2015).

3.6.5. Air quality

Because ozone formation is temperature dependent, projections focusing only on temperature increase generally conclude that ozone-related mortality will increase with additional warming, with the risks higher at 2°C than at 1.5°C (*high confidence*) (Ove Hoegh-Guldberg et al., 2018).

Average Seasonal Population-Weighted Ozone Concentrations in 2017

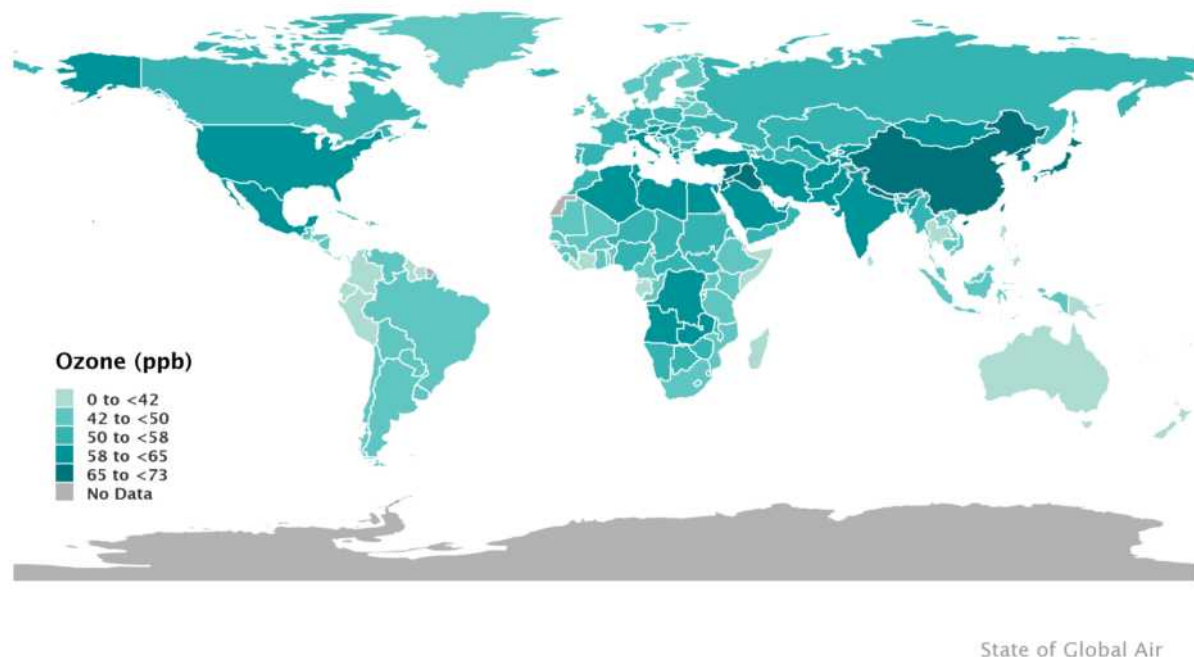


Figure 15: Global ozone concentrations in 2017 (shown as population-weighted seasonal averages) Source: Health Effects Institute, 2019

Due to smaller lungs and a twice as rapid breathing rate up until the age of 12, children inhale proportionally more polluted air. Ozone as one of the increasing pollutants is a trigger of childhood asthma. It can exacerbate asthma symptoms in children. Children may be exposed to higher levels of ozone as they are likely to be outside during peak ozone times (UNICEF, 2015).

Increasing global temperatures increase pollen production and result in higher levels of natural allergens increasing the severity of asthma and other respiratory conditions (UNICEF, 2015).

Smoke from wild fires resulting from extreme heat and drought periods cause 260,000 to 600,000 deaths annually. Due to the higher breathing rate of children under 12, the impact on their health is particularly severe (UNICEF, 2015).

3.6.6. Occupational health

Increasing temperature and higher humidity levels pose additional stress on individuals engaging in physical activity. Safe work activity and worker productivity during the hottest months of the year would be increasingly compromised with additional climate change (medium confidence) (Ove Hoegh-Guldberg et al., 2018).

The Lancet report estimates 153 billion hours of labor were lost in 2017 which equals an increase of 62 billion in comparison to the year 2000. 80% of the losses are linked to the

agricultural sector. The areas most affected are India, southeast Asia, and sub-Saharan Africa, and South America (Watts et al., 2018) which is visible in Figure 16.

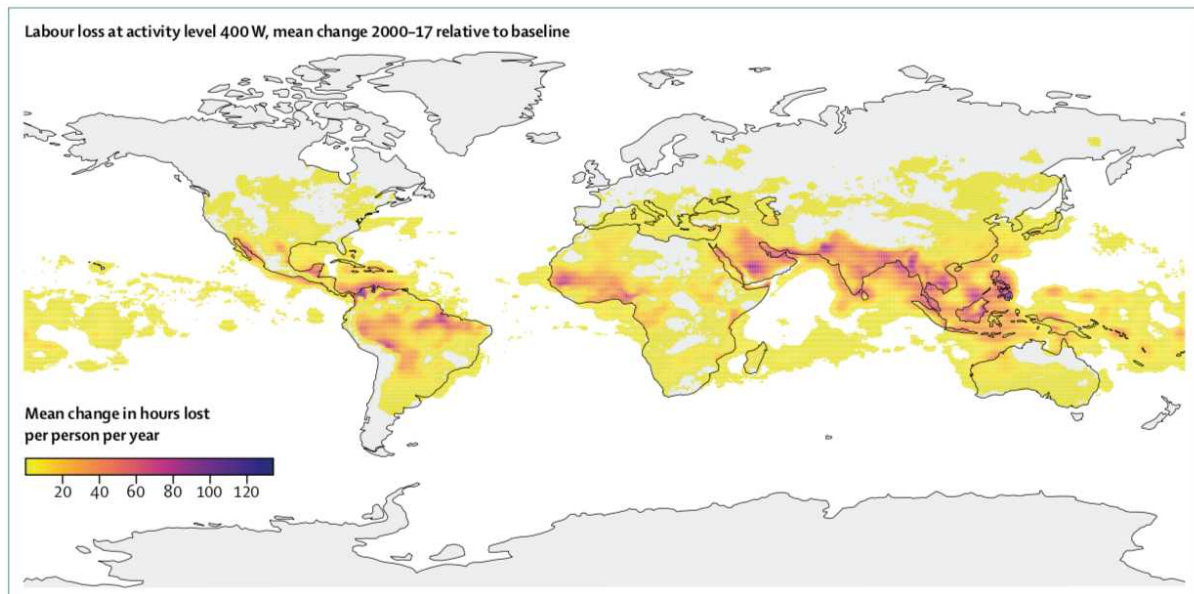


Figure 16: Mean change in total hours of labor lost at the agricultural activity level (metabolic rate of 400 W) over the 2000-2017 period relative to the 1986-2005 baseline. Source: Watts et al., 2018

The impacts of occupational health will become even more pressing with increasing temperatures. According to the IPCC 1.5 special report, the costs of preventing workplace heat-related illnesses through worker breaks suggest that the difference in economic loss between 1.5°C and 2°C could be approximately 0.3% of global gross domestic product (GDP) in 2100 (Ove Hoegh-Guldberg et al., 2018).

3.7. Societal impacts

Drought significantly increases the likelihood of sustained conflict for particularly vulnerable nations or groups, owing to the dependence of their livelihood on agriculture. This is particularly relevant for groups in the least developed countries, in sub-Saharan Africa and in the Middle East (Ove Hoegh-Guldberg et al., 2018).

Conflict

According to the IPCC 5th Assessment Report, climate change can indirectly increase risks of violent conflicts in the form of civil war and inter-group violence by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). Multiple lines of evidence relate climate variability to these forms of conflict (IPCC, 2014).

According to the IPCC 1.5 special report a 1°C increase in temperature or more extreme rainfall increases the frequency of intergroup conflicts by 14%. If the world warms by 2°C–4°C by 2050, rates of human conflict could increase. Some causal associations between violent conflict and socio-political instability were reported from local to global scales and from hour to millennium time frames. A temperature increase of one standard deviation increased the

risk of interpersonal conflict by 2.4% and intergroup conflict by 11.3% (Ove Hoegh-Guldberg et al., 2018).

Migration

Changes in climate can amplify environmentally induced migration both within countries and across borders (medium confidence), reflecting multiple drivers of mobility and available adaptation measures (high confidence). Extreme weather and climate or slow-onset events may lead to increased displacement, disrupted food chains, threatened livelihoods (high confidence), and contribute to exacerbated stresses for conflict (medium confidence) (IPCC, 2019b).

Conflict as well as natural disasters can lead to migration. The social, economic and environmental factors underlying migration are complex and varied; therefore, detecting the effect of observed climate change or assessing its possible magnitude with any degree of confidence is challenging (Ove Hoegh-Guldberg et al., 2018). Since 2008, climate-related displacement has affected an estimated 22.5 million people per year on average - equivalent to 62,000 people every day (UNICEF, 2015).

Even though migration cannot be easily attributed to climate change, the IPCC report does conclude that temperature has had a positive and statistically significant effect on outmigration over recent decades in 163 countries, but only for agriculture-dependent countries (*medium confidence*) (Ove Hoegh-Guldberg et al., 2018). The conflict in Syria follows a multi-year drought period which is one of the stressors that contributed to the outbreak of conflict as recent research shows (Gleick, 2014). The following figure (17) shows asylum seeker flows around the world clearly shows the migration waves particularly leaving Syria (Western Asia).

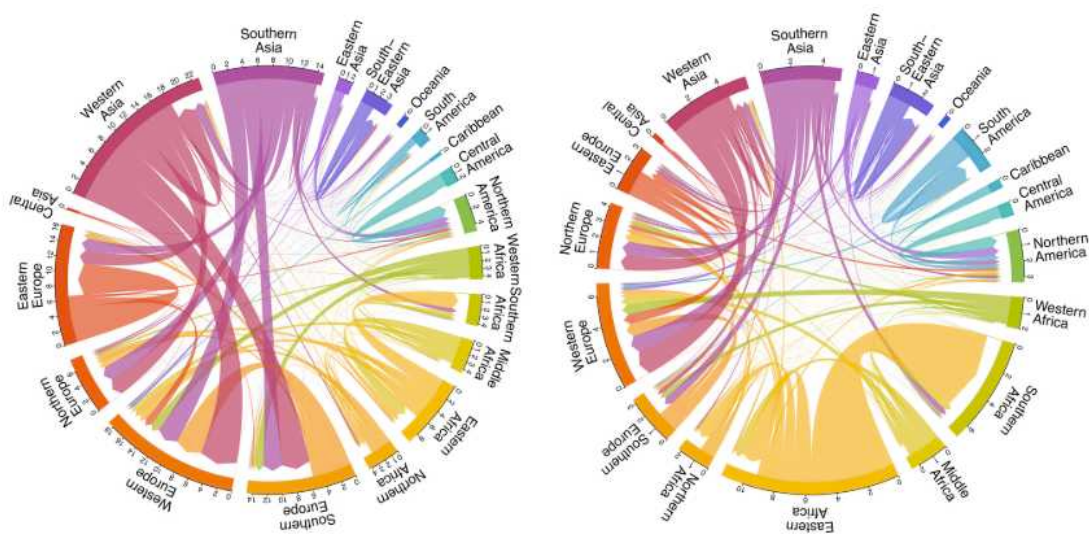


Fig. 2. Asylum seeking flows by world region, 2006–2010 and 2011–2015.

Figure 17: Asylum seeker flow by world region, 2006–2010 and 2011–2015. Source: Abel, Brottrager, Crespo Cuaresma, & Muttarak, 2019

Migration in small islands (internally and internationally) occurs for multiple reasons and purposes, mostly for better livelihood opportunities (high confidence) and increasingly owing to sea level rise (medium confidence) (Ove Hoegh-Guldberg et al., 2018). Kiribati was the first island state to actually purchase land in Fiji to consider the migration of a whole nation as a back-up option for future generations (Caramel, 2014).

Warming levels of 2°C have potential for significant population displacement concentrated in the tropics with possible moving distances greater than 1000 km. A disproportionately rapid evacuation from the tropics could lead to a concentration of population in tropical margins and the subtropics, where population densities could increase by 300% or more (Ove Hoegh-Guldberg et al., 2018).

Educational attainment

Extreme weather events, conflict and migration have an impact on the educational attainment of children, as the economic resources of parents are reduced by e.g. destroyed crops, or the loss of livelihoods. One result may be that parents spend less on their children's schooling or children need to seek work to contribute to the income of the family. Both leads to a decrease in the children's overall educational attainment (Fuller et al., 2018).

Additionally, schools may be damaged or used as shelter during extreme events and are therefore not available for their original purpose (UNICEF, 2015).

Loss of livelihoods and cultural heritage

Sea level rise, loss of sea ice and glaciers, as well as extreme events can have implications of the livelihoods of people around the world.

Tourism as one of the largest industries is already affected by climate change, with increased risks projected under 1.5°C of warming in specific geographic regions and for seasonal tourism including sun, beach and snow sports destinations (very high confidence). Risks for coastal tourism, particularly in subtropical and tropical regions, will increase with temperature-related degradation (e.g., heat extremes, storms) or loss of beach and coral reef assets (high confidence) (Ove Hoegh-Guldberg et al., 2018).

Beyond 1.5°C warming, both ocean warming and acidification increase, with substantial losses likely for coastal livelihoods and industries (e.g., fisheries and aquaculture) (medium to high confidence). Marine systems and associated livelihoods in Small Island Developing States face higher risks at 2°C compared to 1.5°C (medium to high confidence) (Ove Hoegh-Guldberg et al., 2018).

Today at about 1°C global warming, poverty and disadvantage have increased and are likely to increase even further with rising temperatures. At approximately 1.5°C of global warming (2030), climate change is expected to be a poverty multiplier that makes poor people poorer and increases the poverty head count. Climate change alone could force more than 3 million

to 16 million people into extreme poverty, mostly through impacts on agriculture and food prices (Ove Hoegh-Guldberg et al., 2018).

Cultural heritage will be impacted by sea level rise and extreme events. A global analysis of sea level rise risk to 720 UNESCO Cultural World Heritage sites projected that about 47 sites might be affected under 1°C of warming, with this number increasing to 110 and 136 sites under 2°C and 3°C, respectively (Ove Hoegh-Guldberg et al., 2018).

4. Loss and Damage

Long-term risks of coastal flooding and impacts on 2. populations, infrastructures and assets (high confidence), freshwater stress (medium confidence), and risks across marine ecosystems (high confidence) and critical sectors (medium confidence) are projected to increase at 1.5°C compared to present-day levels and increase further at 2°C, limiting adaptation opportunities and increasing loss and damage (medium confidence).

Within the IPCC 1.5 special report Loss and Damage is associated with adverse impacts of climate change on human and natural systems and includes impacts from extreme events (e.g. cyclones) and slow-onset processes (e.g. sea level rise). Loss and damage refer both to economic (loss of assets and crops) and non-economic impacts (biodiversity, culture, health) and irreversible and permanent loss and damage (e.g. loss of coral reefs). The IPCC report addresses both soft and hard limits to adaptation. Soft limits are described as adaptive actions currently not available, while hard limits are adaptive actions which appear infeasible leading to unavoidable impacts (Roy et al., 2018).

For a global warming levels of 1.5°C and 2°C, soft and hard limits will be reached and will be experienced by children living today. Particularly Small Island Developing States populations are threatened to lose their livelihoods forcing people to migrate. In some situations, exceeding the limits of adaptation can trigger escalating losses or result in undesirable transformational changes (medium confidence), such as forced migration (low confidence), conflicts (low confidence) or poverty (medium confidence) (IPCC, 2019b).

System/Region	Example	Soft Limit	Hard Limit
Coral reefs	Loss of 70–90% of tropical coral reefs by mid-century under 1.5°C scenario (total loss under 2°C scenario) (see Chapter 3, Sections 3.4.4 and 3.5.2.1, Box 3.4)		✓
Biodiversity	6% of insects, 8% of plants and 4% of vertebrates lose over 50% of the climatically determined geographic range at 1.5°C (18% of insects, 16% of plants and 8% of vertebrates at 2°C) (see Chapter 3, Section 3.4.3.3)		✓
Poverty	24–357 million people exposed to multi-sector climate risks and vulnerable to poverty at 1.5°C (86–1220 million at 2°C) (see Section 5.2.2)	✓	
Human health	Twice as many megacities exposed to heat stress at 1.5°C compared to present, potentially exposing 350 million additional people to deadly heat wave conditions by 2050 (see Chapter 3, Section 3.4.8)	✓	✓
Coastal livelihoods	Large-scale changes in oceanic systems (temperature and acidification) inflict damage and losses to livelihoods, income, cultural identity and health for coastal-dependent communities at 1.5°C (potential higher losses at 2°C) (see Chapter 3, Sections 3.4.4, 3.4.5, 3.4.6.3, Box 3.4, Box 3.5, Cross-Chapter Box 6, Chapter 4, Section 4.3.5; Section 5.2.3)	✓	✓
Small Island Developing States	Sea level rise and increased wave run up combined with increased aridity and decreased freshwater availability at 1.5°C warming potentially leaving several atoll islands uninhabitable (see Chapter 3, Sections 3.4.3, 3.4.5, Box 3.5, Chapter 4, Cross-Chapter Box 9)		✓

Table 2: Soft and hard adaptation limits in the context of 1.5°C and 2°C of global warming. Source: Roy et al., 2018

Limits to adaptation are also discussed in the IPCC 5th Assessment Report. Chapter 23 on Europe gives a detailed overview of the limits to adaptation for different sectors summed up in the following table:

Area/location	System	Adaptation measures	Limits to adaptation measure(s)	References
Low-altitude/small-size ski resorts	Ski tourism	Artificial snowmaking	Climatic, technological, and environmental constraints; economic viability; social acceptability of charging for previously free skiing; social acceptability of alternatives for winter sport/leisure	Steiger and Mayer (2008); Unbehaun et al. (2008); Steiger (2010, 2011); Landauer et al. (2012)
Thermal power plants/cooling through river intake and discharge	Once-through cooling systems	Closed-circuit cooling	High investment cost for retrofitting existing plants	Koch and Vögele (2009); van Vliet et al. (2012); Hoffman et al. (2013)
Rivers used for freight transport	Inland transport	Reduced load factor of inland ships	Increased transport prices (Rhine and Moselle market)	Jonkeren et al. (2007); Jonkeren (2009)
		Use of smaller ships	Existing barges below optimal size (Rhine)	Demirel (2011)
Agriculture, northern and continental Europe	Arable crops	Changing sowing date as agricultural adaptation	Other constraints (e.g., frost) limit farmer behavior.	Oort (2012)
		Irrigation	Groundwater availability; competition with other users	Olesen et al. (2011)
Agriculture, viticulture	High-value crops	Change distribution	Legislation on cultivar and geographical region	Box 23-1
Conservation; cultural landscapes	Alpine meadow	Extend habitat	No technological adaptation option	Engler et al. (2011); Dullinger et al. (2012)
Conservation of species richness	Movement of species	Extend habitat	Landscape barriers and absence of climate projections in selection of conservation areas	Butchart et al. (2010); Araújo et al. (2011); Filz et al. (2012); Virkkala et al. (2013)
Forests	Movement of species and productivity reduction	Introduce new species	Not socially acceptable; legal barriers to non-native species	Casalegno et al. (2007); Giuggiola et al. (2010); Hemery et al. (2010); García-López and Alluéa (2011)

Table 3: Limits to adaptation to climate change in Europe. Source: (Sari Kovats et al., 2014)

Bibliography

- Abel, G. J., Brottrager, M., Crespo Cuaresma, J., & Muttarak, R. (2019). Climate, conflict and forced migration. *Global Environmental Change*, 54, 239–249. <https://doi.org/10.1016/J.GLOENVCHA.2018.12.003>
- Ahdoot, S., & Pacheco, S. E. (2015). Global Climate Change and Children's Health. *Pediatrics*, 136(5), e1468–e1484. <https://doi.org/10.1542/peds.2015-3233>
- Allen, M. R., Pauline Dube, O., Solecki, W., Aragón-Durand, F., Cramer France, W., Humphreys, S., ... Waterfield, T. (2018). *Special Report on Global Warming of 1.5°C. Capítulo 1: Framing and Context Coordinating*. Australia. Retrieved from https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter1_Low_Res.pdf
- Burke, M., Davis, W. M., & Diffenbaugh, N. S. (2018). Large potential reduction in economic damages under UN mitigation targets. *Nature*, 557(7706), 549–553. <https://doi.org/10.1038/s41586-018-0071-9>
- Caramel, L. (2014). Besieged by the rising tides of climate change, Kiribati buys land in Fiji | Environment | The Guardian. Retrieved August 16, 2019, from <https://www.theguardian.com/environment/2014/jul/01/kiribati-climate-change-fiji-vanua-levu>
- Climate Action Tracker. (2018). 2100 Warming Projections.
- Currie, J., & Deschênes, O. (2016). Children and climate change: Introducing the issue. *Future of Children*, 26(1), 3–9. <https://doi.org/10.1353/foc.2016.0000>
- de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., ... Wollenberg, L. (2018). Chapter 4: Strengthening and implementing the global response. *Global Warming of 1.5C: An IPCC Special Report on the Impacts of Global Warming of 1.5C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*, (June). Retrieved from <http://pure.iiasa.ac.at/id/eprint/15516/>
- Field, C. B., Barros, V. R., Mach, K. J., Mastrandrea, M. D., Aalst, M. van, Adger, W. N., ... Yohe, G. W. (2014). Summary for Policy Makers. In Christopher B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, ... L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1–32). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. <https://doi.org/10.1016/j.renene.2009.11.012>
- Fuller, T. L., Sesink Clee, P. R., Njabo, K. Y., Tróchez, A., Morgan, K., Meñe, D. B., ... Smith, T. B. (2018). Climate warming causes declines in crop yields and lowers school attendance rates in Central Africa. *Science of the Total Environment*, 610–611, 503–510. <https://doi.org/10.1016/j.scitotenv.2017.08.041>
- Gleick, P. H. (2014). Water, Drought, Climate Change, and Conflict in Syria. *Weather, Climate, and Society*, 6(3), 331–340. <https://doi.org/10.1175/WCAS-D-13-00059.1>
- globalwarmingindex.org -- Tracking progress to a safe climate. (n.d.). Retrieved August 1, 2019, from <http://www.globalwarmingindex.org/>
- Health Effects Institute. (2019). *State of Global Air 2019. Special Report*. Boston, MA:Health

- Effects* Institute. Boston, MA. Retrieved from https://www.stateofglobalair.org/sites/default/files/soga_2019_report.pdf
- IPCC. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- IPCC. (2018). *Special Report on 1.5 degrees: Summary for Policymakers*. Aromar Revi. Retrieved from https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf
- IPCC. (2019a). *Chapter 5: Food Security*. Retrieved from https://www.ipcc.ch/site/assets/uploads/2019/08/2f.-Chapter-5_FINAL.pdf
- IPCC. (2019b). *Summary for Policymakers Climate Change and Land An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems WG I WG II WG III IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems Summary for Policymakers Approved Draft Subject to copy edit and layout*. Retrieved from https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf
- King, A. D., & Karoly, D. J. (2017). Climate extremes in Europe at 1.5 and 2 degrees of global warming. *Environmental Research Letters*, 12(11), 114031. <https://doi.org/10.1088/1748-9326/aa8e2c>
- Mengel, M., Nauels, A., Rogelj, J., & Schleussner, C.-F. (2018a). Committed sea-level rise under the Paris Agreement and the legacy of delayed mitigation action. *Nature Communications*, 9(1), 601. <https://doi.org/10.1038/s41467-018-02985-8>
- Mengel, M., Nauels, A., Rogelj, J., & Schleussner, C.-F. (2018b). Sea-level legacy: 20cm more rise by 2300 for each 5-year delay in peaking emissions. Retrieved August 20, 2019, from https://www.pik-potsdam.de/news/press-releases/sea-level-legacy-20cm-more-rise-by-2300-for-each-5-year-delay-in-peaking-emissions/image/image_view_fullscreen
- Moss, R., Babiker, M., Brinkman, S., Calvo, E., Carter, T., Edmonds, J., ... Zurek, M. (2008). *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts and Response Strategies. IPCC Expert Meeting Report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change. Retrieved from <http://www.ipcc.ch>
- Moss, R., Edmonds, J., Hibbard, K., Manning, M., Rose, S., van Vuuren, D., ... Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, 463(7282), 747–756. <https://doi.org/10.1038/nature08823>
- Nauels, A., Rogelj, J., Schleussner, C., & Meinshausen, M. (2017). Linking sea level rise and socioeconomic indicators under the Shared Socioeconomic Pathways. *Environmental Research Letters*, 12(114002), 11. <https://doi.org/10.1088/1748-9326/aa92b6>
- Ove Hoegh-Guldberg, Jacob, D., Taylor, M., & et al. (2018). Impacts of 1.5°C global warming on natural and human systems. In *Global Warming of 1.5 C :An IPCC special report on the impacts of global warming of 1.5 C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change*,. <https://doi.org/10.1093/aje/kwp410>

- Pass Philipsborn, R., & Chan, K. (2018). *Climate Change and Global Child Health*. Retrieved from www.aappublications.org/news
- Roy, J., Tschakert, P., Waisman, H., Abdul Halim, S., Antwi-Agyei, P., Dasgupta, P., ... Suarez Rodriguez, A. G. (2018). Sustainable Development, Poverty Eradication and Reducing Inequalities. In *Global Warming of 1.5 C :An IPCC special report on the impacts of global warming of 1.5 C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change*, (pp. 1–97).
- Sari Kovats, R., Valentini, R., Bouwer, L. M., Georgopoulou, E., Jacob, D., Martin, E., ... Soussana, J.-F. (2014). Europe. In V. R. Barros, C. B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, ... L.L.White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1267–1326). Cambridge, United Kingdom and New York, NY; USA: Cambridge University Press. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap23_FINAL.pdf
- Schiermeier, Q. (2018). Droughts, heatwaves and floods: How to tell when climate change is to blame. *Nature*, 560(7716), 20–22. <https://doi.org/10.1038/d41586-018-05849-9>
- Storlazzi, C. D., Gingerich, S. B., van Dongeren, A. R., Cheriton, O. M., Swarzenski, P. W., Quataert, E., ... McCall, R. (2018). Most atolls will be uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding. *Science Advances*, v. 4(eaap9741), 1–10. <https://doi.org/10.1126/sciadv.aap9741>
- Thomas, A., Pringle, P., Pflleiderer, P., & Schleussner, C.-F. (2017). Tropical Cyclones: Impacts, the link to Climate Change and Adaptation. Climate Analytics. Retrieved from https://climateanalytics.org/media/tropical_cyclones_impacts_cc_adaptation_2.pdf
- UNICEF. (2015). *Unless we act now*.
- United Nations. (2019). *World Population Prospects - Population Division - United Nations*. Retrieved from <https://population.un.org/wpp/DataQuery/>
- United Nations Children's Fund. (2018). Diarrhoeal Disease - UNICEF DATA. *Unicef*. Retrieved from <https://data.unicef.org/topic/child-health/diarrhoeal-disease/>
- Vogel, M. M., Zscheischler, J., Wartenburger, R., Dee, D., & Seneviratne, S. I. (2019). Concurrent 2018 hot extremes across Northern Hemisphere due to human-induced climate change. *Earth's Future*, 2019EF001189. <https://doi.org/10.1029/2019EF001189>
- Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., ... Costello, A. (2018). The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. *Lancet (London, England)*, 392(10163), 2479–2514. [https://doi.org/10.1016/S0140-6736\(18\)32594-7](https://doi.org/10.1016/S0140-6736(18)32594-7)
- World Data Lab. (2019). The World Population Project.

Climate Analytics gGmbH

Ritterstr. 3
10969 Berlin
Germany

T / +49 302 5922 9520

E / contact@climateanalytics.org

